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Wind electric power in the world and perspectives of its development in India

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Abstract

The global market for wind power is expanding faster than any other source of renewable energy. From just 4,800 MW in 1995 raise to fifteen-fold to reach 73,904 MW at the end of 2006. Top five wind electric power generating countries at the end of 2006 were Germany, Spain, United States of America (USA), India and Denmark. Since 1980s, when the first commercial wind turbine was deployed, their capacity, efficiency and visual design have all improved a lot. A modern wind turbine annually produces 180 times more electricity at less than half the cost per unit (kWh) than its equivalent twenty years ago. The largest turbines being manufactured now are of rated power of 5 MW capacity and a rotor diameter of 126 m. Modern turbines are modular and quick to install, whilst wind farms vary in size from a few MW to several hundred MW. Keeping these factors in view, an attempt has been made in this paper to present current advances in wind turbine generator technology. Wind energy scenario in the world in general and in India in particular have been presented. Further the cost components of wind turbine electric generation system have been included.

Keywords: Renewable energy (RE); Wind energy; Wind Turbine Generator (WTG); Electricity; Cost

Contents

1. Introduction

Wind power is now established as an energy source in over 50 countries around the world. In number of countries the proportion of electricity generated by wind power is now challenging the conventional fuels. In Denmark, 20% of the country's electricity is currently supplied by the wind farms. In Denmark, wind power will increase to 50% by 2025, mostly offshore. India has secured fourth position in the world in wind power generation after Germany, Spain and USA.

India's geographic location has several advantages for the extensive use of the renewable energy sources. India's

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geographic location is Southern Asia, bordering the Arabian Sea and the Bay of Bengal, between Burma and Pakistan and Geographic coordinates 20 °N, 77 °E. The length of the coastline is 7000 km.The length of land boundaries is 14,103 km, India share boundaries with Bangladesh 4053 km, Bhutan 605 km, Burma 1463 km, China 3380 km, Nepal 1690 km, and with Pakistan 2912 km. India's population of 1,095,351,995 is growing at an annual rate of 1.38%(July 2006 estimated). The economy has posted an average growth rate of more than 7% in the decade since 1996, reducing poverty by about 10 percentage points. India achieved 8.5% GDP growth in 2006, significantly expanding manufacturing. India has terrain upland plain (Deccan Plateau) in south, flat to rolling plain along the Ganges, deserts in west, Himalayas in north. India's elevation extremes have lowest point of 0 m at Indian Ocean and highest point at Kanchenjunga of 8,598 m. The climate varies from tropical monsoon in south to temperate in north [1]. Wind resources in India are influenced by the strong south-west summer monsoon, which starts in May–June, when cool, humid air moves towards the land and the weaker north-east winter monsoon, which starts in October, when cool, dry air moves towards the ocean. During the period March to August, the winds are uniformly strong over the whole Indian Peninsula, except the eastern peninsular coast. Wind speeds during the period November to March are relatively weak, though higher winds are available during a part of the period on the Tamil Nadu coastline [2]. The total power generating capacity of India has grown from 1300 MW in 1950 to about 1,32,329.21 MW in March 2007. India has per capita consumption of electricity of 606 kWh/year (year 2004–2005) [3–4].

In the power sector, there is significant synergy between the three core drivers shaping future development of the sector. These are: (i) meeting a growing demand for electricity at affordable cost; (ii) ensuring long-term security of primary energy supply through an appropriate mix of sources; and (iii) minimizing the environmental impacts — at the local, regional and global level [5].

Table 1
Estimated potential and cumulative achievements up to 31.12.2006 [12]

S. no.	Sources/systems	Estimated potential	Achievements up to 31.12.2006
I	Power from renewables		
	A. *Grid-interactive renewable power*		
1	Solar photovoltaic power	–	2.74 MW
2	Wind power	45,000 MW	6270.00 MW
3	Small hydro power (up to 25 MW)	15,000 MW	1860.79 MW
4	Biomass power	16,000 MW	500.00 MW
5	Bagasse cogeneration	5000 MW	595.83 MW
6	Biomass gasifier	–	1.00 MW
7	Energy from urban and industrial waste	2700 MW	34.95 MW
	Sub Total (A)	83,700 MW	9265.31 MW
	B. *Distributed renewable power*	–	
7	Biomass/cogen. (non-bagasse)	–	30.30 MW
8	Biomass gasifier	–	82.65 MW
9	Energy recovery from waste	–	11.03 MW
	Sub Total (B)	–	123.98 MW
	Total (A + B)		9389.29 MW
II	Decentralized energy systems		
10	Family type biogas plants	120 lakh	38.90 lakh
11	Solar photovoltaic programme	20 MW/Sq.km.	
	(i) Solar street lighting system	–	54659 nos.
	(ii) Home lighting system	–	280813 nos.
	(iii) Solar lantern	–	403058 nos.
	(iv) Solar power plants	–	1859.80 kWp
12	Solar thermal programme		
	(i) Solar water heating systems	140 million sq. m. collector area	1.65 million sq.m. collector area
	(ii) Solar cookers	–	6.00 lakhs
13	Wind pumps	–	1137 nos.
14	Aero-generator/hybrid systems	–	494.68 kW
15	Solar photovoltaic pumps	–	7015 nos.
III	Demonstration and publicity		
16	Energy parks		472 nos.
17	Akshay Urja shops		401 nos.
18	District advisory committees		550 nos.
IV	Remote village electrification		2237/591 villages/hamlets

In December 1997, at the United Nations Framework Convention on Climate Change in Kyoto, Japan, about 160 nations reached the first-ever agreement to limit emissions of greenhouse gases, including carbon dioxide. Most industrialized nations committed to reduce average national emissions, in order to achieve the goals of the Kyoto Protocol. To accomplish this multilateral commitment, many nations have turned to renewable/alternative sources of energy thus opening huge markets for carbon-free energy [6]. The increase in greenhouse gas emissions and the resulting climatic changes, which occur globally, have understandably caused world-wide concern. According to an assessment by the Intergovernmental Panel on Climate Change, the rise in the average temperature by the end of the next century i.e., 2100 will be in the range 1–3.5°C. This has serious implications for the entire ecosystem of the world. This fact has led to a series of initiatives at international levels to develop eco-friendly alternatives that would meet the needs of the present generation without compromising the abilities of the future generations. The developed nations have contributed a greater share of the emissions of carbon dioxide, leading to global warming. But the current trends in the developing nations are very alarming and, if uncontrolled, developing countries will contribute half of the annual greenhouse gases. This calls for urgent measures for minimizing, if not replacing, the reliance on fossil fuels to meet the increasing energy requirements. It is for this reason that the non-conventional renewable sources of energy have caught the attention of scientists and researchers. Global warming, caused largely by greenhouse gas emissions from fossil fuel energy generating systems, is a major concern.

India needs to develop alternate fuels considering the aforesaid two concerns. The search for alternative fuels that would ensure sustainable development on the one hand and energy security on the other began in the 1970s itself. Sustainable development demands a sustainable supply of energy resources that in the long term, is readily and sustainably available at reasonable cost in the country. Sustainable development could only be achieved by provision of high quality and environmentally responsible energy on time, at a reasonable price.

Consequently, new and renewable sources of energy have emerged as an option. The importance of increasing the use of renewable energy sources was recognized in India in the early 1970s since oil crisis. Ever since the 1980s, emphasis has been laid on the development, trial and induction of renewable energy technologies for different sectors [7]. Sale of Certified Emission Reductions (CERs) at a price of 5.5 Euros per ton CO_2 improves an Indian wind power plant project's internal rate of return (IRR) by 10% [8]. Chandrasekar and Kandpal [9] briefly summarized the responses received on the desirable role of various institutions towards large scale dissemination of renewable energy technologies in the country.

The RE such as solar, wind, biomass and small hydro is getting greater recognition in meeting the day-to-day energy requirements for cooking, lighting, process heat, captive power of domestic, commercial and industrial sectors. Besides, the renewable energy sector is now an

Table 2
Installed wind power capacity in the world [17]

Ranking total 2006	Country	Additional capacity 2006 (MW)	Growth rate 2006 (%)	Total capacity end 2006 (MW)	Total capacity end 2005 (MW)	Ranking total 2005
1	Germany	2194	11.9	20,622	18,428	1
2	Spain	1587	15.8	11,615	10,028	2
3	USA	2454	26.8	11,603	9149	3
4	India	1840	41.5	6,270	4430	4
5	Denmark	8	0.3	3,136	3128	5
6	China	1145	90.9	2,405	1260	8
7	Italy	405	23.6	2,123	1718	6
8	United Kingdom	610	45.1	1,963	1353	7
9	Portugal	628	61.4	1,650	1022	11
10	France	810	106.9	1,567	757	13
11	Netherlands	336	27.5	1,560	1224	9
12	Canada	768	112.4	1,451	683	14
13	Japan	354	34.0	1,394	1040	10
14	Austria	146	17.8	965	819	12
15	Australia	238	41.1	817	579	15
16	Greece	183	31.9	756	573	16
17	Ireland	147	29.6	643	496	18
18	Sweden	54	10.6	564	510	17
19	Norway	55	20.4	325	270	19
20	Brazil	208	729.6	237	29	34
	Rest	730	48.4	2,238	1508	
	Total	14,900	25.3	73,904	59,004	

established sector in India with significant installed grid quality renewable power, which has reached 9389.29 MW during 2006. Of this, wind alone contributes to about 6270 MW and small hydropower has touched 1860.79 MW. Besides this, a large number of decentralized renewable energy systems such as biogas plants, solar water heating systems, biomass gasifiers, solar photovoltaic systems, etc. have been promoted under various schemes of the Ministry of New and Renewable Energy (formerly Ministry of Non-Conventional Energy Sources). The year 2006 has been significant for the Ministry from the view point of promoting solar water heating systems, wind power and biomass power installations, giving a wide publicity through establishing Renewable Energy Clubs in Engineering and Technology Institutions [10]. Wind power development in the country has been spurred by a mix of promotional measures. The Government has introduced a package of incentives, which includes fiscal concessions such as 80% accelerated depreciation, tax holiday for power generation projects, concessional customs and excise duty, liberalized foreign investment procedures, etc. SERCs (State Electricity Regulatory Commissions) of Andhra Pradesh, Madhya Pradesh, Karnataka and Maharashtra have so far announced preferential tariffs for wind power. Maharashtra Electricity Regulatory Commission (MERC), Andhra Pradesh Electricity Regulatory Commission (APERC), Karnataka Electricity Regulatory Commission (KERC), Madhya Pradesh Electricity Regulatory Commission (MPERC) and Orissa Electricity Regulatory Commission (OERC) have directed that each distribution licensee shall purchase a minimum quantum of electricity annually from renewable sources expressed as a percentage of its total consumption. Rajasthan Govt. has recently modified their policy for non-conventional energy projects including for wind energy [11]. Table 1 shows the renewable power potential and achievements in India up to 31.12.2006.

RE facilities like wind power plants will be utilized for successor generation to globally supplement electrical power — by power electronics (PE) conversion, interconnection, energy storage, and automation [13]. Ramakumar et al. [14] highlighted wind electricity's rapidly

Table 3
Indian wind turbine manufacturers [21]

S. No.	Indian manufacturers with location	Model	Capacity (kW)
1	NEG-MICON India Chennai	NM 48/750 RD: 48.2m HH: 45/50/55m	750
		Tower type: Conical steel NM 54/950 RD: 54.5m HH: 44/55/70m Tower type: Tubular steel	950
		NM 82/ V 82-1.65 MW 1 speed MK II RD: 82m HH: 59/68.5/70/78m Tower type: Tubular steel	1650
2	Elecon Engineering Company Ltd., Vidyanagar Gujarat	T600-48 RD: 48m HH: 50/ 55/ 60m Tower type: Tubular	600
3	Enercon (India) Ltd., Mumbai	E-33 RD: 33.4 m HH: 49.04/49.92 m Tower type: Tubular steel	330
		E-40/6.44/E3 RD: 44m HH:50m Tower type: Tubular steel	600
		E48 RD: 48m HH: 50/57/75 m Tower type: For HH 50/57/75 m—Tubular steel &75m -precast concrete	800
4	GE Wind Energy INDIA, Bangalore	GE 1.5sle 50 HZ RD: 77.0m HH: 61.4 m/85 m Tower type: Tubular steel	1500

Table 3 (*continued*)

S. No.	Indian manufacturers with location	Model	Capacity (kW)
5	M/s Pioneer Asia Wind Turbines Chennai	Gamesa Eolica G52–850 kW 50 Hz/60 Hz RD:52m HH: 44/55/65m Tower type: Tubular steel G58–850 kW 50 Hz/60 Hz RD: 58m HH: 44/55/65m Tower type: Tubular steel	850
6	Suzlon Energy Ltd., Pune	Sulzon S64 /1000 kW RD:64m HH:65m Tower type: Lattice	1000
		Sulzon S 64/1250 KW RD: 64m HH: 65m Tower type: Lattice	1250
		Sulzon S 66 /1250 kW RD: 66m HH: 65m Tower type: Lattice	1250
		Sulzon S88/2100 kW RD:88m HH:80m Tower type: Tubular steel	2100
		Sulzon 600 KW RD: 52 m HH: 75 m Tower type: Lattice	600
		S 70/1250 KW RD : 69.1 m HH : 75 m Tower type: Tubular	1250
		S82 RD: 82m HH: 78.3m Tower type: Tubular	600
7	Shriram EPC Ltd.,	SEPC 250 T RD: 28.5 HH: 41.2 Tower type: Lattice	250
8	M/s Vestas RRB INDIA LTD New Delhi	V39-500 kw RD: 47 m HH: 40/45/50m Tower type: For HH 40/45/50 m—Tubular steel 40/45/50m-Lattice	500
		Pawan Shakthi-600 kW RD: 47m HH: 50m Tower type: Lattice	600
		Vestas V27 – 225 kW RD: 27m HH: 31.5m Tower type: Conical tubular	225
9	L M GLASFIBRE Hoskote	Manufacturer of blades for Wind Electric generators	

Wind turbine model are given in order as—Model no.; RD: rotor diameter; HH: hub height; tower type.

evolving influx into conventional power systems on a global scale and concluded that wind power, as a safe, carbon-neutral resource, is the best choice to fill the electricity generation gap. Why wind energy is best has been realized due to these significant factors [3,15].

- The project is environment friendly.
- Good wind potential to harness wind energy.
- A permanent shield against ever increasing power prices. The cost per kWh reduces over a period of time as against rising cost for conventional power projects.
- The cheapest source of electrical energy (on a leveled cost over 20 years).
- Least equity participation required, as well as low-cost debt is easily available to wind energy projects.
- A project with the fastest payback period.
- A real fast track power project, with the lowest gestation period and a modular concept.
- Operation and maintenance (O&M) costs are low.
- No marketing risks, as the product is electrical energy.
- A project with no investment in manpower.
- It brings diverse fuel source that is free of cost and free of pollution.

2. The state of wind power engineering

In terms of new electric capacity, wind power is the leader (leaving aside large hydropower). Global wind power generation capacity grew by 25% after 24% in 2005 from 59 GW in 2005 to 73.9 GW in 2006 [16]. More than half of the global wind power additions were in three

Table 4
Wind power potential in India [26]

S. no.	State	Gross potential (MW)	Technical potential (MW)
1	Andhra Pradesh	8275	1920
2	Gujarat	9675	1780
3	Karnataka	6620	1180
4	Kerala	875	605
5	Madhya Pradesh	5500	845
6	Maharashtra	3650	3040
7	Orissa	1700	780
8	Rajasthan	5400	910
9	Tamil Nadu	3050	1880
10	West Bengal	450	450
	Total	45,195	13,390

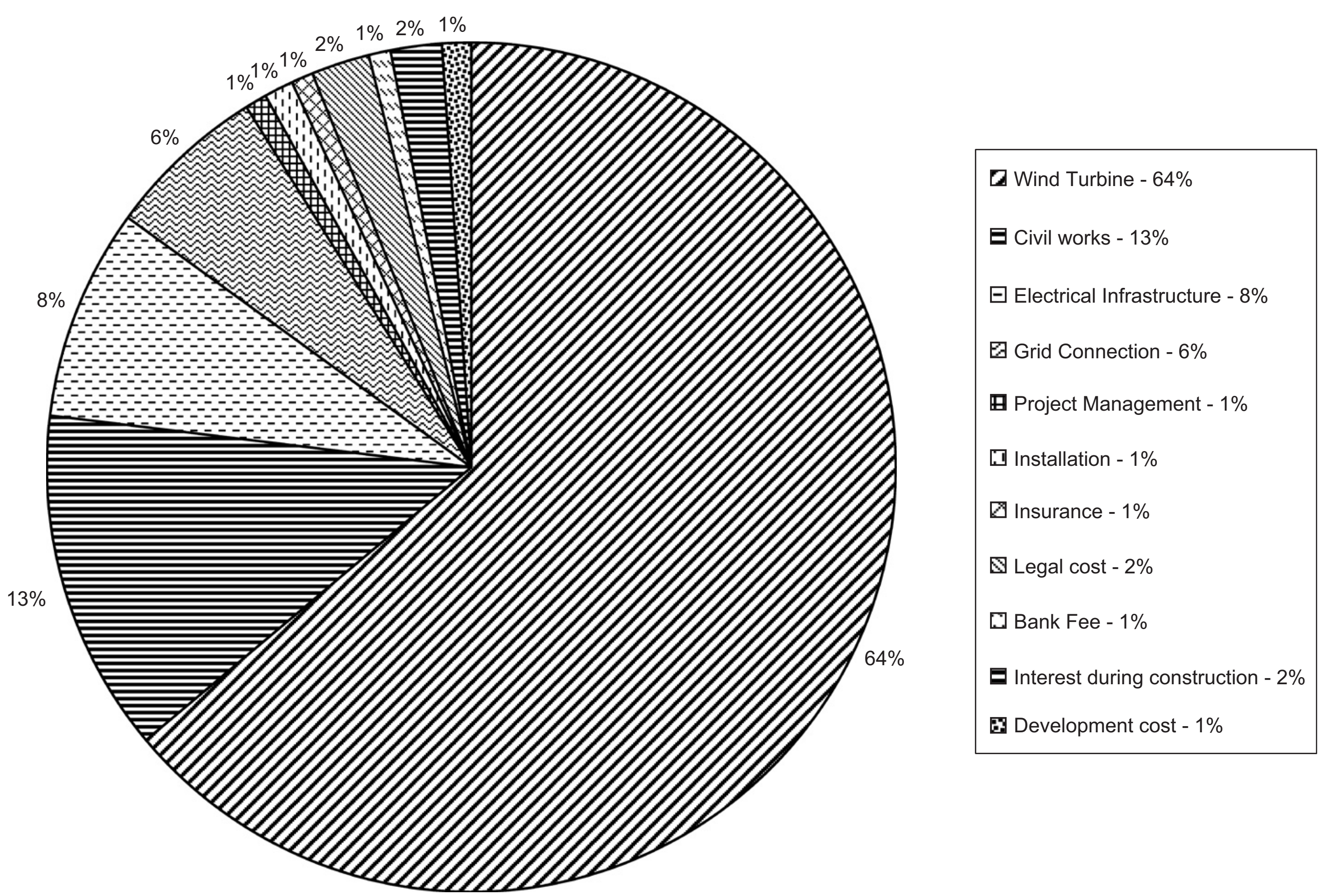

Fig. 1. Capital Cost Breakdown of a Typical 5 MW Onshore Project.

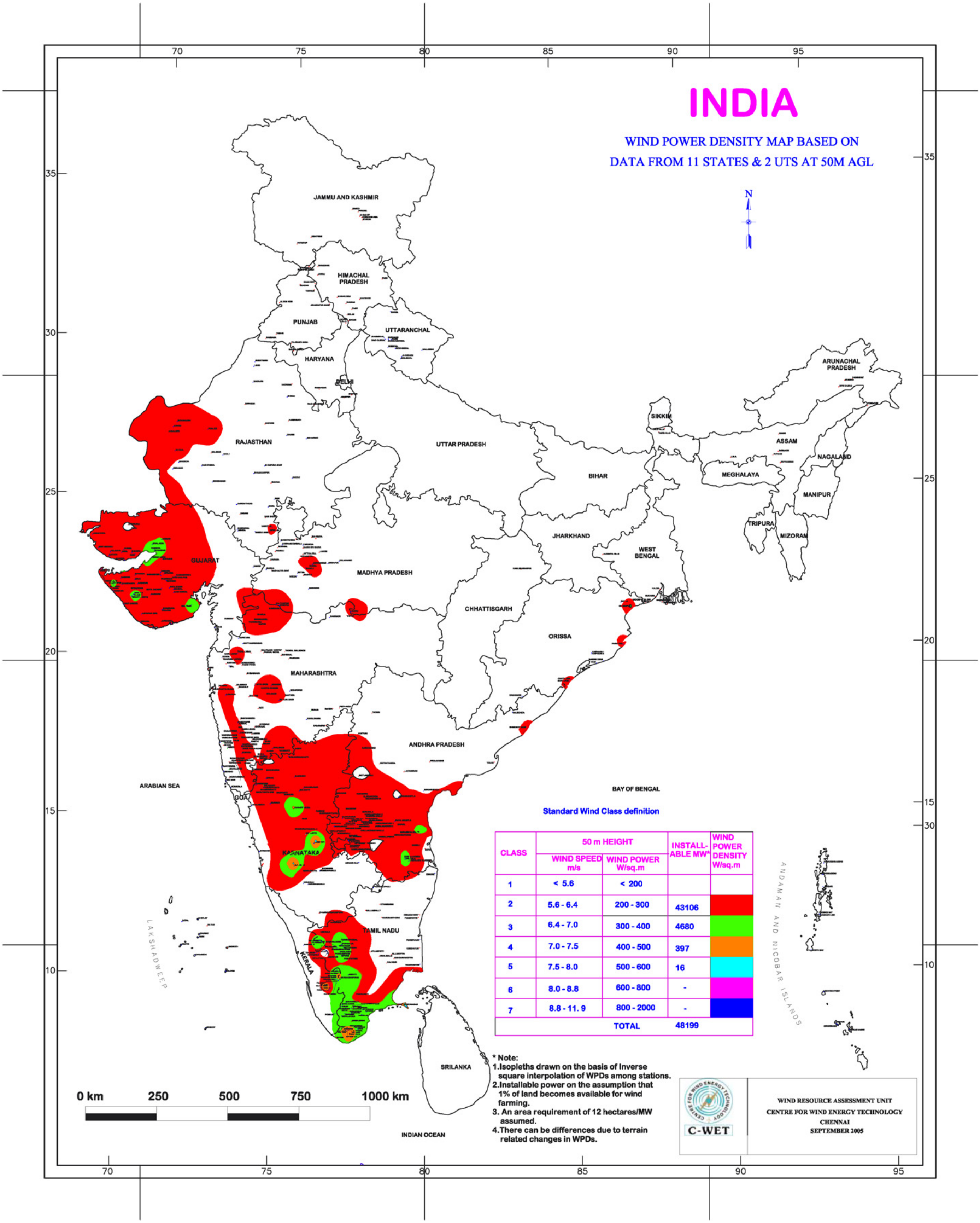

Fig. 2. Wind power density map of India [15].

countries-the United States, Germany and Spain. Five countries added more than 1000 MW: the United States of America (2454 MW), Germany (2194 MW), India (1840 MW) and Spain (1587 MW) were able to secure their leading market positions and China (1145 MW) joined the group of the now top five markets and is now number five in terms of added capacity, showing a market growth of 91%. Four countries added more than 500 MW and showed excellent growth rates: France (810 MW, 107% growth), Canada (768 MW, 112%), Portugal (628 MW, 61%) and the United Kingdom (610 MW, 45%). The most dynamic market in 2006, Brazil, faced its long expected take off and added 208 MW which equals a seven fold increase of installed capacity within one year [17]. The data presented in Table 2 indicate the general conditions of development of wind power in several countries.

3. Wind turbine production

The wind turbines that generate electricity today are new and innovative. Their success story began with a few technical innovations, such as the use of synthetics to make rotor blades. Developments in the field of aerodynamics, mechanical/electrical engineering, control technology, and electronics provide the technical basis for wind turbines commonly used today. Since 1980, wind turbines have been becoming larger and more efficient. In 1950, Professor Ulrich Hütter applied modern aerodynamics and modern fiber optics technology to the construction of rotor blades on the wind turbines in his experimental system. In the 1980s, the Danes developed small turbines with a nominal output of 20 kW to 100 kW [18]. Major factors that have accelerated the wind power technology development are as follows.

- High-strength composite fiber material for constructing low-cost, light weight and long length blades for larger swept area.
- Falling prices of the power electronics.
- Variable-speed operation of electrical generators to capture maximum energy.
- Improved plant operation, pushing the availability up to 95%.
- Economy of scale, as the turbines and plants are getting large in size.
- Accumulated field experience (the learning curve effect) improving the capacity factor.

Kenisarin et al. [19] presented the main manufacturers of large wind turbines in the world. In India M/s. Suzlon is the top wind turbine manufacturer. Suzlon commissioned its Vankusawade wind park in the Satara District of India's Maharashtra state having 201 MW of capacity. Suzlon's Dhule wind park site, located approximately 30 km from the town of Nandurbar in Maharashtra, is spread across a vast, undulating expanse. The site has

Table 5
Year-wise wind power installed capacity (MW) of India [15,27]

S. no	State	Upto March 1992	During 1992–1993	During 1993–1994	During 1994–1995	During 1995–1996	During 1996–1997	During 1997–1998	During 1998–1999	During 1999–2000	During 2000–2001	During 2001–2002	During 2002–2003	During 2003–2004	During 2004–2005	During 2005–2006	As on Dec. 2006
1	Andhra	0.550	0	0	5.425	38.925	9.39	1.5	6	6	3.8	0.7	0	6.2	21.8	0.5	122
2	Gujarat	14.515	1.63	10.625	37.745	51.158	31.137	20.1	0	0	0	0	6.2	28.9	51.5	84.6	401
3	Karnataka	0.550	0	0	0	2.025	3.270	11.165	2.625	14.59	10.4	24	55.7	84.9	201.5	173.8	746
4	Kerala	0	0	0	0	2.025	0	0	0	0	0	0	0	0	0	0	2.025
5	Madhya	0.59	0	0	0	6.3	2.7	2.7	6.155	4.14	0	0	0	0	6.3	11.4	55
6	Maharasthra	1.1	0	0	1.5	0	2.77	0.225	23.34	50.345	110.6	209.4	2	6.3	48.8	545.1	1284
7	Rajasthan	0	0	0	0	0	0	0	0	2	5.3	8.8	44.6	117.8	106.3	73.3	441
8	Tamilnadu	22.31	11.07	50.465	190.86	281.68	119.7	31.14	17.765	45.675	41.9	44.9	132.8	371.3	675.4	857.6	3216
9	West Bengal	0	0	0	0	0	0	0	0	0	0.5	0.6	0	0	0	0	1.6
10	Others	1.565	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.6
	Total	41.18	12.7	61.09	235.53	382.11	169	66.83	55.88	143	172.5	287.4	241.3	615.3	1111.6	1746.3	6270

Table 6
State-wise & station- wise data of wind monitoring stations for potential sites in India [28,29]

Cum No.	S. Station no.		District	Latitude N		Longitude E		Altitude	Mast height	Mean annual wind speed at 20/25 m	Mean annual wind power at 20/25 m	Wind power density at 50 m
				Deg	Min	Deg	Min	(m)	(m)	(m/s)	(W/m^2)	(W/m^2)
Andaman & Nicobar Islands (1 station)												
1	1	Keating Point	Nicobar	09	15	92	46	2	20	4.46	114	>175
		Andra Pradesh (35 stations)										
2	1	Alangarapeta	Anantapur	14	46	77	47	360	25	5.77	244	272
3	2	Badhrampalli Kottala	Kurnool	14	55	77	24	440	25	5.92	248	277
4	3	Banderlapalli	Kurnool	15	01	78	04	438	25	5.78	240	320
5	4	Bhimunipatnam*	Visakapatnam	17	49	83	24	120	20	5.31	195	282
6	5	Borampalli	Anantapur	14	30	77	09	550	25	5.38	163	219
7	6	Burugula	Kurnool	15	08	77	57	540	25	5.11	147	216
8	7	Chinnababayapalli	Anantapur	13	57	77	37	750	25	5.14	132	206
9	8	Jamalamadugu*- 1	Cuddapah	14	49	78	23	195	25	4.86	161	265
10	9	Jamalamadugu- 2	Cuddapah	14	44	78	22	380	25	5.17	165	248
11	10	Kadavakallu*- 1	Anantapur	14	51	77	55	349	25	6.14	303	325
12	11	Kadavakallu – 2 (Ref. Stn)	Anantapur	14	47	77	57	395	25	6.47	274	333
13	12	Kakula Konda	Chittoor	13	43	79	21	981	20	6.42	332	541
14	13	Kodumuru	Kurnool	15	43	77	45	410	25	5.79	225	270
15	14	Kondamithipalli*	Kurnool	15	03	78	03	449	25	5.89	252	349
16	15	Korrakodu	Anantapur	14	46	77	15	460	25	5.19	146	220
17	16	M.P.R. Dam*	Anantapur	14	53	77	31	400	20	5.53	228	269
18	17	Madugupalli	Anantapur	14	42	77	51	440	25	5.19	152	266
19	18	Mustikovala	Anantapur	14	15	77	32	600	20	5.61	201	237
20	19	Nallakonda*	Anantapur	14	07	77	34	757	25	6.33	276	324
21	20	Narasimha Konda	Nellore	14	30	79	52	100	20	5.58	186	403
22	21	Nazeerabad*	Rangareddy	17	11	77	55	670	25	5.83	176	232
23	22	Pampanoor Thanda*	Anantapur	14	38	77	24	490	25	5.44	182	232
24	23	Payalakuntla	Cuddapah	14	53	79	02	340	20	5.58	230	257
25	24	Ramagiri*-I	Anantapur	14	16	77	31	580	20	5.42	205	308
26	25	Ramagiri -II (Ref.Stn.)	Anantapur	14	17	77	31	573	25	5.88	197	226
27	26	Ramagiri- III	Anantapur	14	22	77	32	550	20	5.39	190	246
28	27	Siddanagatta	Kurnool	15	34	78	03	490	25	4.97	126	231
29	28	Singanamala	Anantapur	14	46	77	44	469	20	6.61	366	392
30	29	Talaricheruvu	Anantapur	14	57	78	03	360	25	5.03	144	298
31	30	Tallimadugula	Anantapur	14	22	77	32	540	25	6.17	260	288
32	31	Tirumala	Chittoor	13	40	79	22	880	20	5.67	226	374
33	32	Tirumalayapalli*	Cuddapah	14	54	78	11	442	20	5.28	154	285
34	33	Ulindakonda	Kurnool	15	38	77	59	430	25	4.87	130	225
35	34	Vajrakarur*-I	Anantapur	14	58	77	19	509	20	5.41	173	243
36	35	Vajrakarur-II	Anantapur	14	58	77	19	509	50	5.40	154	202
Gujrat (38 station)												
37	1	Adesar	Kachchh	23	33	70	57	41	20	4.33	093	307
38	2	Amrapar* (Gir)	Junagarh	21	11	70	25	140	20	5.46	147	241
39	3	Amrapar (Seth)	Jamnagar	21	44	70	03	160	20	5.33	151	221
40	4	Bamanbore*- 2	Surendranagar	22	26	71	03	200	20	5.64	171	243
41	5	Bayath	Kachchh	22	56	69	11	20	20	4.90	118	300

Table 6 (*continued*)

Cum No.	S. Station no.		District	Latitude N		Longitude E		Altitude	Mast height	Mean annual wind speed at 20/25 m	Mean annual wind power at 20/25 m	Wind power density at 50 m
				Deg	Min	Deg	Min	(m)	(m)	(m/s)	(W/m^2)	(W/m^2)
42	6	Bhandariya*	Junagarh	22	04	69	41	80	20	5.42	162	208
43	7	Butavadar	Jamnagar	21	57	70	11	120	20	4.56	098	240
44	8	Dhank* -1-1 (Ref.Stn.)	Rajkot	21	47	70	06	180	20	6.78	312	414
45	9	Dhank -2	Rajkot	21	48	70	07	208	20	6.97	327	367
46	10	Gala*	Jamnagar	22	15	70	07	124	20	5.49	175	254
47	11	Godladhar*	Rajkot	22	03	71	19	240	20	5.40	144	345
48	12	Haripar*	Jamnagar	22	16	69	38	40	20	5.57	160	210
49	13	Harshad	Jamnagar	21	50	69	22	12	20	5.56	164	239
50	14	Jafrabad*	Amreli	20	54	71	24	20	20	4.86	137	242
51	15	Jamanvada*	Junagarh	23	35	68	36	60	20	5.17	149	299
52	16	Jasapar	Amreli	21	21	71	06	230	20	4.78	104	214
53	17	Kagavad	Rajkot	21	48	70	41	132	20	5.13	141	212
54	18	Kalyanpur*	Jamnagar	22	03	69	24	80	20	6.14	208	327
55	19	Khambada	Rajkot	21	48	71	08	180	20	4.86	126	204
56	20	Kukma*	Kachchh	23	10	69	40	220	20	5.33	150	239
57	21	Lamba	Jamnagar	21	54	69	19	20	20	5.56	164	232
58	22	Limbara	Surendranagar	22	32	70	59	160	20	5.31	166	227
59	23	Mahidad*	Surendranagar	22	17	71	12	330	25	5.97	178	231
60	24	Moti Sindholi*	Kachchh	23	09	68	47	10	20	4.86	118	311
61	25	Mundra*	Kachchh	22	47	69	43	2	20	5.42	168	303
62	26	Nani Kundal	Bhavnagar	21	55	71	28	154	20	5.56	163	278
63	27	Navadra-1 (Ref.Stn.)	Jamnagar	21	57	69	16	24	20	5.78	183	297
64	28	Navi Bander*	Jamnagar	21	27	69	47	1	20	5.42	153	213
65	29	Okha*	Jamnagar	22	27	69	03	2	20	5.39	150	260
66	30	Okhamadhi	Jamnagar	22	06	69	06	12	20	5.28	129	209
67	31	Poladiya*	Kachchh	23	04	69	13	150	20	5.72	177	278
68	32	Ratabhe	Surendranagar	22	56	71	02	70	20	4.86	123	212
69	33	Rojmal-2	Bhavnagar	–	–	–	–	–	20	5.11	129	317
70	34	Sanodar*	Bhavnagar	21	33	72	06	230	20	6.24	197	373
71	35	Sinai*	Kachchh	23	03	70	04	57	20	5.77	183	244
72	36	Surajbari*	Kachchh	23	13	70	42	10	20	5.42	184	444
73	37	Suvarda	Jamnagar	22	23	70	07	90	20	5.61	166	243
74	38	Warshamedi	Rajkot	22	58	70	34	3	20	5.67	192	>499
Karnataka (27 station)												
75	1	B.B. Hills*	Chikmangalur	13	26	75	46	1840	20	7.44	498	581
76	2	Chalamatti*	Dharwar	15	18	74	03	705	20	5.94	189	268
77	3	Channavadayanpura	Mysore	11	57	76	36	940	25	5.66	154	243
78	4	Chikkodi* (Ref.Stn.)	Belgaum	15	25	74	35	760	25	6.44	264	298
79	5	Gokak*	Belgaum	16	10	74	48	723	20	5.33	168	336
80	6	Hanamsagar*	Raichur	15	54	76	02	628	20	5.72	173	270
81	7	Hanumanhatti*	Belgaum	15	53	74	43	895	20	5.64	165	294
82	8	Horti*	Bijapur	17	07	75	44	620	25	5.50	173	202
83	9	Jogimatti* (Ref.Stn.)	Chitradurga	14	10	76	24	1120	20	8.42	498	632
84	10	Kappattaguda*	Gadag	15	14	75	43	959	25	6.92	311	423
85	11	Khamkarhatti*	Belgaum	15	47	74	36	841	25	5.64	159	217
86	12	Malgatti	Raichur	16	25	74	47	780	20	5.44	156	335
87	13	Mannikere*	Belgaum	15	58	74	28	923	20	6.75	252	315

88	14	Mavinhunda*	Belgaum	16	25	74	47	780	20	6.15	212	>212
89	15	Nargund	Gadag	15	44	75	22	788	25	8.37	530	652
90	16	Ramgad	Bellary	15	08	76	27	980	25	5.07	134	263
91	17	Sangundi*	Bijapur	16	15	75	44	625	20	5.19	153	259
92	18	Sogi	Bellary	14	54	75	59	890	25	6.61	246	284
93	19	Subramanyahalli*	Bellary	15	01	76	33	1026	25	5.87	214	409
94	20	Arasinagundi (KPCL)	Davanagar	14	29	76	21	780	30	7.50	392	>392
95	21	Bullenahalli-I (KPCL)	Tumkur	13	25	76	40	1060	30	5.89	168	>168
96	22	Bullenahalli-II (KPCL)	Tumkur	13	24	76	41	1060	30	5.65	195	>195
97	23	Gujannur (KPCL)	Bellary	14	58	75	54	684	30	6.49	240	>240
98	24	Jogimatti (KPCL)	Chitradurga	14	12	76	25	1040	30	8.62	582	>582
99	25	Madekeripura (KPCL)	Chitradurga	14	13	76	27	800	30	7.54	365	>365
100	26	Sogi-A (KPCL)	Bellary	14	55	75	59	845	30	7.38	415	>415
101	27	Sogi-B (KPCL)	Bellary	14	54	75	59	895	30	6.80	271	284
Kerala (16 stations)												
102	1	Kailasammedu	Idukki	09	51	77	10	1160	20	6.44	251	375
103	2	Kanjikode*	Palakkad	10	47	76	47	120	20	6.28	218	296
104	3	Kolahalamedu	Idukki	09	40	76	56	1000	20	4.69	146	222
105	4	Kotamala	Palakkad	10	40	76	36	150	20	5.33	154	239
106	5	Kottathara	Palakkad	11	07	76	39	750	20	5.47	207	297
107	6	Kulathummedu*	Idukki	09	45	77	10	1140	20	5.61	181	349
108	7	Kuttikanam	Idukki	09	35	76	59	1000	20	4.58	140	243
109	8	Nallasingam*	Palakkad	11	05	76	43	840	20	6.36	324	456
110	9	Panchalimedu	Idukki	09	32	76	57	950	20	5.61	258	327
111	10	Parampukettimedu	Idukki	09	54	77	12	1160	20	7.58	470	721
112	11	Ponmudi	Trivandrum	08	46	77	08	1070	20	5.14	216	226
113	12	Pullikanam	Idukki	09	44	76	52	1100	20	5.06	178	200
114	13	Ramakalmedu	Idukki	09	49	77	14	920	20	8.25	532	535
115	14	Sakkulathumedu	Idukki	09	52	77	13	1040	20	7.93	531	561
116	15	Senapathi	Idukki	09	57	77	11	1240	20	5.39	189	339
117	16	Tolanur	Palakkad	10	42	76	30	100	20	4.36	115	231
Lakshadweep (8 stations)												
118	1	Agathi	Lakshadweep	10	51	72	11	1	20	5.11	179	253
119	2	Amini	Lakshadweep	11	05	72	44	4	20	4.83	140	>150
120	3	Bitra	Lakshadweep	11	35	72	12	1	20	4.58	173	>258
121	4	Chetlat	Lakshadweep	11	43	72	43	1	20	5.28	172	267
122	5	Kadmat	Lakshadweep	11	13	72	47	1	20	5.00	169	282
123	6	Kalpeni	Lakshadweep	10	05	73	39	1	20	4.50	125	302
124	7	Kavarathi	Lakshadweep	10	33	72	38	1	20	5.00	161	283
125	8	Minicoy	Lakshadweep	08	17	73	04	1	20	4.83	162	>162
Madhya Pradesh (7 station)												
126	1	Jamgodrani	Dewas	22	59	76	10	560	20	5.06	130	222
127	2	Kukru*	Betul	21	30	77	29	1118	20	5.28	157	255
128	3	Mahuriya*	Shajapur	23	50	76	06	504	25	5.28	171	217
129	4	Mamatkheda	Ratlam	23	41	75	03	560	20	5.57	169	255
130	5	Nagda*-2 (Ref.Stn.)	Dewas	22	54	76	03	673	25	6.25	219	371
131	6	Sendhva*	Khargon	21	38	75	03	540	20	5.03	163	215
132	7	Valiyarpani*	Khargon	21	40	74	57	510	20	5.25	191	287
Maharashtra (31 station)												
133	1	Alamprabhu Pathar*	Kolhapur	16	46	74	22	790	25	5.69	164	224
134	2	Amberi*	Satara	17	35	74	17	980	25	6.39	237	275
135	3	Aundhewadi	Nasik	19	46	73	50	876	25	6.58	294	>295

Table 6 (*continued*)

Cum No.	S. Station no.		District	Latitude N		Longitude E		Altitude	Mast height	Mean annual wind speed at 20/25 m	Mean annual wind power at 20/25 m	Wind power density at 50 m
				Deg	Min	Deg	Min	(m)	(m)	(m/s)	(W/m^2)	(W/m^2)
136	4	Bhud	Sangli	17	20	74	42	834	25	5.48	160	224
137	5	Brahmanvel*	Dhule	21	10	74	12	595	25	6.42	278	324
138	6	Chakla	Nandurbar	21	19	74	19	380	25	6.58	242	323
139	7	Chalkewadi	Satara	17	37	73	49	1185	20	5.61	206	218
140	8	Dhalgaon*	Sangli	17	08	74	59	810	20	5.89	216	260
141	9	Dongerwadi*	Sangli	16	54	74	50	830	25	5.94	179	284
142	10	Gawalwadi	Nasik	20	06	73	43	740	20	5.28	140	278
143	11	Gude Panchagani*	Sangli	17	07	73	59	903	20	5.50	178	296
144	12	Kankora	Aurangabad	19	59	75	27	920	25	5.56	127	204
145	13	Kas	Satara	17	44	73	49	1240	25	5.69	194	277
146	14	Kavdya Donger*	Ahmadnagar	19	00	74	32	900	25	6.44	224	277
147	15	Khandke*	Ahmadnagar	19	08	74	53	920	20	5.44	146	250
148	16	Kolgaon*	Ahmadnagar	18	50	74	43	800	25	5.69	177	238
149	17	Lonavla*	Pune	18	47	73	23	560	20	4.31	122	285
150	18	Mandhardeo	Satara	18	02	73	53	1280	25	5.39	153	206
151	19	Matrewadi*	Satara	17	11	73	56	898	25	5.78	211	253
152	20	Palsi	Satara	17	20	73	40	970	25	5.24	137	254
153	21	Panchgani	Satara	17	55	73	48	1372	20	5.11	133	205
154	22	Panchpatta	Ahmadnagar	19	44	73	53	1054	25	5.70	201	236
155	23	Raipur	Dhule	21	02	74	22	500	25	5.25	162	214
156	24	Rohina	Latur	18	27	76	56	676	25	5.57	149	226
157	25	Sautada*	Bid	18	48	75	20	800	25	5.89	167	223
158	26	Takarmauli*	Dhule	21	05	74	03	624	25	5.78	186	224
159	27	Thoseghar* (Ref.Stn.)	Satara	17	35	73	53	1140	20	6.03	229	>250
160	28	Vankusawade*-I	Satara	17	27	73	50	1100	25	5.89	231	293
161	29	Vankusawade-II	Satara	–	–	–	–	–	50	5.68	188	249
162	30	Varekarwadi	Sangli	17	13	73	59	920	20	5.84	204	216
163	31	Vijayadurg*	Sindhudurg	16	30	73	20	100	20	5.44	207	253
Orissa (6 stations)												
164	1	Chandipur	Baleshwar	21	32	87	01	5	20	4.39	120	315
165	2	Chatrapur	Ganjam	19	18	84	58	9	20	4.00	106	264
166	3	Damanjodi*-2	Koraput	18	50	83	00	1340	20	5.18	150	250
167	4	Gopalpur	Ganjam	19	16	84	54	7	20	4.50	124	265
168	5	Paradwip	Cuttack	20	23	86	41	6	20	5.06	153	289
169	6	Puri*	Puri	19	47	85	48	3	20	4.86	137	214
Rajasthan (7 station)												
170	1	Devgarh*	Chittorgarh	24	03	74	39	520	25	5.52	151	281
171	2	Harshnath	Sikar	27	30	75	10	910	25	5.73	206	>206
172	3	Jaisalmer*-1	Jaisalmer	26	56	70	55	231	25	4.94	159	274
173	4	Jaisalmer-2 (Ref.Stn.)	Jaisalmer	26	56	70	54	231	20	5.50	182	311
174	5	Khodal	Barmer	26	22	71	13	200	20	4.72	135	229
175	6	Mohangarh	Jaisalmer	27	17	71	13	155	20	4.31	117	243
176	7	Phalodi*	Jodhpur	27	06	72	19	250	20	4.83	142	261
Tamil Nadu (43 station)												
177	3	Achankuttam*	Tirunelveli	08	57	77	29	139	20	5.17	270	437
178	4	Alagiyapandiyapuram*	Nellaikattabom	08	56	77	39	85	20	5.81	301	487

179	5	Andhiyur	Coimbatore	10	36	77	11	380	20	5.31	177	271
180	6	Andipatti*	Madurai	10	00	77	33	320	20	5.28	266	346
181	5	Arasampalayam	Coimbatore	10	51	77	02	370	20	5.69	195	291
182	6	Ayikudy*	Nellaikattabom	09	00	77	21	179	20	5.94	305	536
183	7	Edayarpalayam*	Coimbatore	10	51	77	02	370	20	6.22	273	398
184	8	Ennore*	Chengalpattu	13	15	80	20	1	20	5.36	139	243
185	9	Gangaikondan	Tirunelveli	08	51	77	46	40	25	5.11	246	338
186	10	Kannankulam	Tirunelveli	08	09	77	36	20	25	5.92	238	375
187	11	Kattadimalai	Kanyakumari	08	14	77	33	90	20	6.58	312	488
188	12	Kayattar-I	Chidambaranar	08	58	77	44	94	20	5.64	294	413
189	13	Kayattar-II (Ref.Stn.)	Chidambaranar	08	56	77	43	105	25	5.69	285	356
190	14	Kethanur-1	Coimbatore	10	55	77	15	439	20	5.86	259	376
191	15	Kethanur-2 (Ref.Stn.)	Coimbatore	10	55	77	15	403	25	5.47	189	345
192	16	Kumarapuram	Tirunelveli	08	16	77	35	80	25	6.11	288	408
193	17	Mangalapuram*	Tirunelveli	09	03	77	22	182	20	6.19	312	423
194	18	Meenakshipuram	Madurai	09	53	77	16	464	20	4.56	224	334
195	19	Mettukadai*	Periyar	10	53	77	23	350	20	5.00	184	281
196	20	Muppandal-1(Ref.Stn.)	Kanyakumari	08	16	77	33	105	20	7.08	406	712
197	21	Muppandal-2	Kanyakumari	08	15	77	33	103	25	6.19	243	410
198	22	Muttom	Kanyakumari	08	08	77	19	70	25	4.75	116	234
199	23	Myvadi*	Coimbatore	10	36	77	19	341	20	5.44	251	376
200	24	Naduvakkurichi*	Nellaikattabom	09	07	77	30	163	20	4.67	157	244
201	25	Nettur	Nellaikattabom	08	54	77	33	100	25	5.53	338	419
202	26	Onamkulam *	Chidambaranar	08	57	77	51	100	25	5.53	247	292
203	27	Ottapidaram*	Chidambaranar	08	54	78	01	40	20	5.14	221	378
204	28	Ovari*	Tirunelveli	08	17	77	52	21	20	5.08	160	221
205	29	Panakudi	Tirunelveli	08	19	77	33	140	20	6.36	366	469
206	30	Pongalur*	Coimbatore	10	58	77	21	388	20	5.31	213	309
207	31	Poolavadi*	Coimbatore	10	44	77	17	321	20	5.89	283	445
208	32	Poosaripatti*	Coimbatore	10	40	77	07	380	25	5.36	168	254
209	33	Puliyamkulam*	Nellaikattabom	08	19	77	44	35	20	5.25	188	343
210	34	Pushpathur-2	Dindigul	10	32	77	25	363	25	4.47	128	254
211	35	Rameswaram	Ramanathpuram	09	14	79	21	4	20	6.64	290	604
212	36	Sankaneri*	Tirunelveli	08	12	77	40	30	25	6.28	258	388
213	37	Sembagaramanpudur	Kanyakumari	08	15	77	29	40	20	6.03	300	476
214	38	Servallar Hills	Nellaikattabom	08	42	77	21	312	20	4.94	207	313
215	39	Sultanpet	Coimbatore	10	52	77	11	380	20	5.28	203	206
216	40	Talayathu	Nellaikattabom	08	48	77	40	105	20	5.69	324	422
217	41	Thannirpandal	Coimbatore	10	57	77	19	400	20	5.06	216	>330
218	42	Tuticorin	Tuticorin	08	50	78	08	3	20	4.89	148	245
219	43	Vakaikulam*	Tuticorin	08	45	78	00	32	20	4.61	167	256
Uttaranchal (1 station)												
220	1	Bachelikhal	Garhwal	30	09	78	34	965	20	5.02	144	244
West Bengal (1 station)												
221	1	Gangasagar*	24 Parganas	21	38	88	04	3	25	4.83	155	225

*Micro Survey Report available with C-WET (Source C-WET).

already crossed 400 MW in installed capacity featuring mainly the company's highly successful S64-1.25 MW model, and plans to add a further 600 MW capacity are in progress. At 1000 MW Suzlon's Dhule Wind Park in India is poised to take its place among the world's largest wind parks when complete [20]. Table 3 shows the wind turbines which are available now for wind power generation in India [21].

4. The investment costs

In every country the price of electricity depends not only on the cost of generation but also on the many different factors that affect the market, such as energy subsidies and taxes. The cost of generating electricity comprises of:

- Capital costs (the cost of building the power plant and connecting it to the grid).
- Running costs (such as buying fuel and operation and maintenance) and
- The cost of financing (how the capital cost is repaid).

With wind energy, and many other renewables, the fuel is free. Therefore once the project has been paid for, the only costs are operation and maintenance and fixed costs, such as land rental. The capital cost is high, between 75% and 90% of the total for onshore projects. The capital cost breakdown of a typical 5 MW onshore project is shown in Fig. 1. Although the cost varies between different countries, the trend everywhere is the same—wind energy is getting cheaper. The cost is coming down for various reasons. The turbines themselves are getting cheaper as technology improves and the components can be made more economically. The productivity of these newer designs is also better, so more electricity is produced from more cost-effective turbines. There is also a trend towards larger machines. This reduces infrastructure costs, as fewer turbines are needed for the same output [22].

The three most important factors that determine the cost of wind-generated electricity are:

- Wind speed — higher the speed, lower the cost.
- Capital cost of installed capacity — lower the per MW capital cost of turbines, lower the cost of electricity.
- Size of wind farms — larger the wind farm, lower the cost of energy.

Other important factors are, cost of financing, as wind energy is capital intensive; and policies related to transmission, tax and the environment [23]. The capital cost of wind energy projects in the country ranges from Rs. 4 crore to Rs. 4.5 crore per MW. The cost of power generation is estimated to be Rs. 2 to Rs. 2.50 per kWh, depending on the site [24].

5. Wind power potential in India

The kinetic energy of the wind is a promising source of renewable energy with significant potential in many parts of the world. The total annual kinetic energy of air movement in the atmosphere is estimated to be around 3×10^{15} kWh or about 0.2% of the solar energy reaching the earth. The maximum technically usable potential is estimated theoretically to be 30×10^{12} kWh/year or about 35% of the current world total energy consumption [25]. Scientific surveys are being intensified to identify specific viable and potential sites. A recent study undertaken to assess the potential, places it at about 45,000 MW. Assuming a grid penetration of 20%, a technical potential of about 13390 MW is already available for exploitation in the potential States shown in Table 4 [26]. Fig. 2 shows the wind power density map of India [15]. India had undertaken one of the world's largest efforts for wind resource assessment. Table 5 shows year wise installed wind power capacity of India [15,27]. State-wise and Station-wise Data of Wind Monitoring Stations for potential sites in India is shown in Table 6 [28,29]. Sites with annual wind power density more than 200 W/m^2 are generally considered as viable.

6. Conclusions

Like other developing countries, the energy demand in India is increasing rapidly. Continued economic development and exponential population growth are driving energy demand faster than India can produce it. Presently, major share of electricity generation in India is from thermal. Renewable energy sources in India are in abundance, which can fulfill the growing energy demand. Wind energy is a clean, safe, easy to maintain and sustainable method of generating electricity. Every unit of electricity from a wind turbine displaces one that would otherwise be generated from fossil fuels, and thus prevents the emissions of several greenhouse gases, key contributors to climate change. Wind energy in India has an extremely bright future and there is no doubt that, in the renewable energy sector, wind power would play a predominant role in adding clean and non-polluting energy to the country's grid. Improvement in WTG design and installation of capacitor on WTG helps to penetrate more amount of power in weak grid. Similarly, plant load factor is less during monsoon season in India and availability of wind speed is high through out the day during monsoon in India. This helps to improve the reliability of grid.

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